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RADIAL GROWTH AND HEALTH CONDITION OF NORWAY SPRUCE (*PICEA ABIES* (L.) KARST.) STANDS IN RELATION TO CLIMATE (SILESIAN BESKIDS, CZECH REPUBLIC)

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Abstract: The research was conducted in selected spruce stands of the Silesian Beskids aged over 70 at altitudes from 403 m a.s.l. to 794 m a.s.l. in 2008. The samples were taken and processed in compliance with standard dendrochronological methodology. Tree rings were measured and the tree-ring curves were synchronized using the PAST4 application. The age trend was removed in the ARSTAN application and the climatic influences were modelled in the DendroClim application. The regional standard tree-ring chronology shows an obvious decrease in the radial increment from the beginning of the 1970s to the mid-1990s. The gradual increase in radial increment which followed in the second half of the 1990s was interrupted in 2000, 2003, and 2006. Most of the years with the decreased radial increment have been confirmed by the analysis of significant negative years. The radial increment statistically significantly correlates with the precipitation in July and September of the previous year, precipitation in June of the year in question and precipitation during the vegetation period. Moreover, the growth of spruce is statistically significantly affected by temperatures in October of the previous year and March of the year in question. Additionally, the paper includes habitual monitoring of trees and the volume of salvage cutting in these districts. The condition of the habit of trees and the development of salvage cuttings agree with the hypothesis about strong stress load or its considerable increase in 2003 and the following years.

Keywords: the Silesian Beskids, spruce, precipitation, temperature, tree-ring, habitual diagnostic.

1. INTRODUCTION

Norway spruce (*Picea abies* (L.) Karst.) is one of the most significant European tree species and also a tree species with the highest number of various health and growth problems which have appeared in the last decades. It has quite specific requirements concerning precipitation and generally it is one of the species that are quite sensitive to the climate. The relation between the climate and radial increment has recently been explored by e.g. Mäkinen *et al*. (2000, 2001, 2002), Vitas (2004), Koprowski and Zielski (2006), Savva *et al*. (2006), Büntgen *et al*. (2007).

At the beginning of this century, signs of *Picea abies* decline started to appear in the Silesian Beskids, especially in forest district Jablunkov. The Polish side of the Silesian Beskids had already seen this decline at the beginning of the 1990s. The decline has a character of a complex disease brought about by synergic influence of abiotic, biotic and anthropogenic factors. The basic symptoms are: yellowing, defoliation, decrease in radial increment and dying of individual trees and also groups of trees in stands of various ages, in some cases with final biotic mortality factors being present (*Armillaria spp., Ips typographus, Ips duplicatus, Pityogenes chalcographus, etc*.), in other cases without identifiable mortality factors.

The signs of dying grew stronger after 2003. As this was a very dry year, a hypothesis was created that within the complex of factors the climate plays a role of high or even essential importance, in other words, that the climate plays an essential role in the increase in the stress load after 2003 and to a great extent it initiates the above described decline.

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The objective of the study was to find out the dynamics of the radial growth in the Jablunkov district of the Silesian Beskids during the last 45 years, i.e. in the period for which the relevant climatic data is available, and to identify the growth responses to the climate; further, to put the knowledge gained from the tree-ring chronology in connection with the data gained concurrently regarding the health condition and the process of dying of *Picea abies* with the aim to confirm or deny the above mentioned hypothesis about the significance of climatic factors.

2. MATERIAL AND METHODS

The research was conducted in selected spruce stands of the Silesian Beskids (**Fig. 1**) aged over 70 at altitudes from 403 m a.s.l. to 794 m a.s.l. in 2008. The dendrochronological analysis and habitual diagnostics were carried out in the first three districts (Nýdek, Písek, Horní Lomná); the other districts were only used for habitual diagnostics. In total, 270 samples were taken for the dendrochronological analysis. There were 378 trees selected for habitual diagnostics (**Table 1**).

The samples were taken using the Pressler borer and processed in correspondence with the standard dendrochronological methodology (Cook and Kairiukstis, 1990). Bore holes were made at 1.3 m above the ground. The sampling was conducted along the contour line so that the increment could not be influenced by the presence of compression wood. At each of the plots, 30 samples were taken for dendrochronological analyses (in total 270 samples), one sample from each tree. The samples were fixed into wooden slats and their surface was ground off. The wood samples were then measured using a specialized measuring table equipped with an adjustable screw device and an impulsemeter recording the interval of table top shifting and in this way also the tree ring width. Measuring and synchronizing of tree-ring sequences were carried out using the PAST4 (©Sciem) application. The annual wood increments were measured with 0.01 mm accuracy.

After measuring a comparison (cross-dating) of individual measured curves was made. Cross-dating is finding the synchronous positions of two tree-ring series. Both series are compared in all possible mutual positions. The aim is to identify the tree rings in each sample created in the same year. If there is a synchronous position, it is demonstrated by a sufficiently high similarity in the area where they overlap (Cook and Kairiukstis, 1990). The excellently correlating curves were used to create the average tree-ring curve. The curve sets off the common

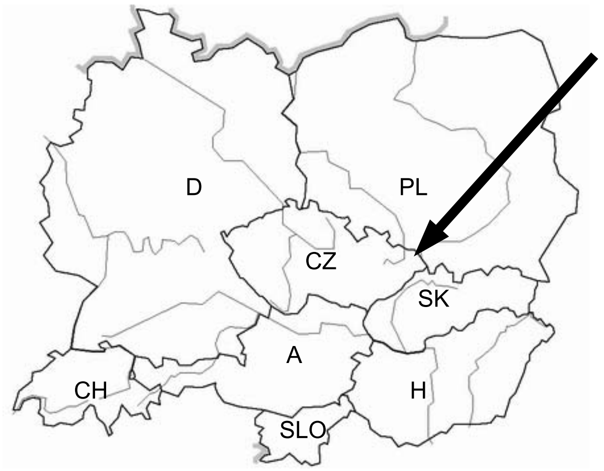

Fig. 1. *Silesian Beskids*

Table 1. *A detailed overview of all areas*

Forest district	Nýdek			Písek				Horní Lomná	
Title of plot	**N1**	**N2**	**N3**	**P1**	**P2**	**P3**	**P4**	**HL1**	**HL2**
Number of trees	30	30	30	30	30	30	30	30	30
Forest vegetation zone	5	5	5	5	5	5	5	5	5
Edaphic category	mesotrophica	lapidosa mesotrophica	mesotrophica	lapidosa mesotrophica, mesotrophica	lapidosa mesotrophica, lapidosa acidophila	mesotrophica	mesotrophica	lapidosa mesotrophica, mesotrophica	mesotrophica
GPS	N 49°40,879 E 18°46,984	N 49°40,177 E 18°47,036	N 49°39,709 E 18°48,030	N 49°34,709 E 18°48,951	N 49°39,709 E 18°48,032	N 49°34,304 E 18°49,964	N 49°35,551 E 18°48,973	N 49°30,422 E 18°38,367	N 49°35,551 E 18°48,975
Altitude (m a.s.l.)	778	673	601	650	753	549	759	765	794
Slope orientation	SW 225°	NW 315°	S 180°	NE 45°	SW 225°	SW 225°	SW 225°	SE 135°	NW 315°
Forest district	Mosty u Jablunkova				Dolní Lomná			Rovina	
Title of plot	**M1**	**M2**	**M3**	**M4**	**DL1**	**DL2**	**DL3**	**R1**	**R2**
Number of trees	12	12	12	12	12	12	12	12	12
Forest vegetation zone	5	5	5	5	5	4	5	4	4
Edaphic category	mesotrophica, acidophila	mesotrophica	acidophila	mesotrophica	trophica	mesotrophica	illimerosa trophica	variohumida mesotrophica	variohumida mesotrophica
GPS	N 49°30,635 E 18°44,493	N 49°31,101 E 18°44,408	N 49°30,569 E 18°43,562	N 49°30,730 E 18°43,361	N 49°31,462 E 18°42,429	N 49°31,552 E 18°44,460	N 49°31,642 E 18°44,225	N 49°36,267 E 18°43,420	N 49°36,822 E 18°42,180
Altitude (m a.s.l.)	666	706	726	757	725	607	648	403	418
Slope orientation	S 180°	E 80°	W 270°	ESE 115°	EEN 80°	NEE 60°	E 90°	N 340°	N 230°

extremes related to climatic changes and reduces all the other oscillations caused by other factors. The degree of similarity between the tree-ring curves was evaluated using the correlation coefficient and the parallelism coefficient (*Gleichläufigkeit*). These calculations facilitate the optical comparison of both curves, which is crucial for the final dating (Rybníček *et al*., 2010).

Individual tree-ring series were exported from PAST4 to the ARSTAN application (Grissino–Mayer *et al*., 1992), where they were detrended, autocorrelation was removed and the regional standard tree-ring chronology and the regional residual tree-ring chronology were created. The removal of the age trend was carried out using a two-step detrending method (Holmes *et al*., 1986). First, a negative exponential function or a linear regression curve, which best express the change of the growth trend with age, were used (Fritts *et al*., 1969). Other potentially non-climatically conditioned fluctuations of values of radial increments, brought about by e.g. competition or forester's interference, were balanced using the cubic spline function (Cook and Peters, 1981). The chosen length of the spline function was 67% of the detrended tree-ring curve length (Cook and Kairiukstis, 1990).

From the tree-ring series detrended in this way the regional index residual tree-ring chronology was created in the ARSTAN application. The chronology has low values of autocorrelation. Also the standard regional tree-ring chronology was established. The range of the created regional tree-ring chronologies is from 1886 to 2007.

To model the radial increments in dependence on the climatic characteristics the DendroClim application was used (Biondi and Waikul, 2004). Before the modelling itself it was necessary to convert the output data from ARSTAN to the input format of DendroClim.

The regional index residual tree-ring chronology and the climatic time series of average monthly temperatures and precipitation for the Silesian Beskids were used to calculate the correlations of values of radial increments with climatic factors. The climatic time series of average monthly temperatures and precipitation was built from Jablunkov meteorological station data (N 49°35´38.04; E 18°44´39.12). The series covers the period from 1961 to 2007. They were always calculated from May of the previous year till August of the year in question, i.e. the period of 16 months. It is the period that should have the highest influence on the radial increments in that particular year.

The statistical comparison of time series of radial increments and the time series of climatic factors will enable us to find out what the average influence of the studied climatic parameters on the increments is in the long term. The influences that occur with a low frequency and that also have fundamental effect on the tree growth do not have to be demonstrated in the correlation analysis to a statistically significant degree (Kienast *et al*., 1987). To establish these effects the analysis of negative pointer years was used. The negative pointer year is defined as an extremely narrow tree ring with the growth reduction exceeding 40% in comparison with the average tree-ring width in the four previous years; strong increment reduction was found in at least 20% of the trees from the area (Kroupová, 2002).

In the habitual diagnostics the following were especially evaluated: the total defoliation, the defoliation of the primary structure, the percentage of secondary shoots, the presence and extent of yellowing and the browning, and the stem damage (Cudlín *et al*., 2001).

In the representative number of trees basic habitual characteristics according to Cudlín *et al*. (2001) were evaluated by means of binoculars. First, the growth habit of a tree was described, namely, social position, type of branching, type of the tree top, crown form, the presence of stem, crown and top breaks. Crowns were visually divided to three parts: upper juvenile part, central production part and lower saturation part. In the juvenile part, its form was evaluated (according to the modified method of Lesinski and Landman (1995)), in the production part, total defoliation, defoliation of the primary structure, the percentage of secondary shoots and types of damage (Cudlín *et al*., 2001). Subsequently, discoloration was assessed, i.e. yellowing and browning – the percentage was estimated of the total volume of an assimilatory apparatus with the presence of discoloration (in an interval of 5%).

To be able to assess the extent of spruce decline in the region relevantly, including its mortality, the data on salvage cutting occurrences were collected for the period from 1999 to 2008. The data were acquired from the Forest Economy Records and then processed. The forestry records used two categories for the cuttings connected with the described unspecific decline of spruce: "dead trees without attack" and "salvage cutting, tracheomycosis (*Armillaria spp.*)".

3. RESULTS

When comparing the average tree-ring curves of the individual districts, the statistical indicators show high values. When the curves overlap by at least sixty rings, the critical value of Student's t-distribution with 0.1% level of significance is 3.46 (Šmelko and Wolf, 1977). The values of our t-tests are much higher than 3.46, which show a high reliability of the synchronization (**Table 2**). The correctness of the synchronization is also proved by the agreement of the average tree-ring curves in most of the extreme values (**Fig. 2**). Thanks to these results, only one average tree-ring curve representing the radial increment of all three districts together could be created.

Table 2. *Synchronization of average tree-ring curves of individual district*

Compared curves	T-test (according to Baillie & Pilcher)	T-test (according to Hollstein)	Gleichläufigkeit (%)
Nýdek x Písek	16.27	16.12	77
Nýdek x Horní Lomná	10.18	9.21	69
Písek x Horní Lomná	15.03	12.6	76

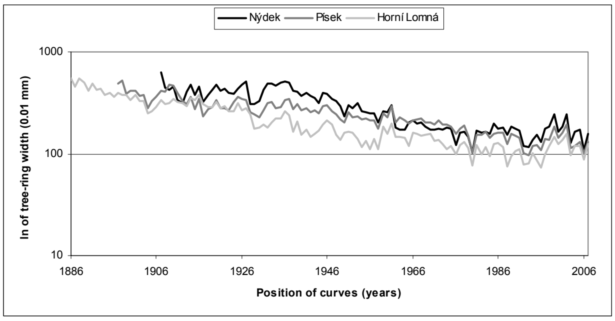

Fig. 2. *Synchronization of average tree-ring curves of individual district*

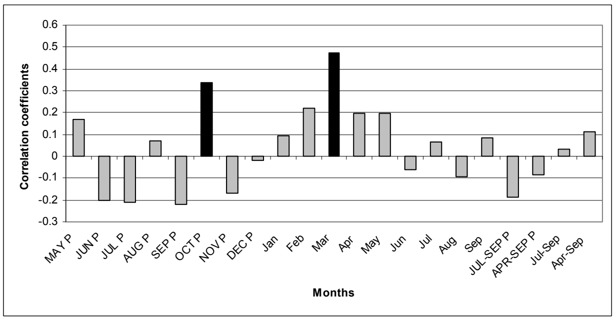

Fig. 3. *The values of correlation coefficients of the regional residual index tree-ring chronology with the average monthly temperatures from May of the previous year (P) to September of the year in question; moreover, the period of July-September of both the previous year (P) and the year in question and the vegetation period (April-September) of both the previous (P) year and the year in question were added for the period of 1962-2006. Values highlighted in black are statistically significant (α = 0.05).*

The correlations of the radial increment with average monthly temperatures and precipitation have only positive statistically significant values. The radial increment statistically significantly correlates with temperatures in October of the previous years and in March of the year in question (**Fig. 3**). The correlation of the radial increment with temperatures of the vegetation period (April-September) either of the previous year or the year in question shows no statistically significant values. The growth of spruce is statistically significantly affected by the precipitation in July and September of the previous year and the precipitation in June of that particular year (**Fig. 4**). The comparison of the radial increment with the precipitation within the vegetation period of the previous year and the year in question, and also with a three-month period (July, August, September) of the previous year shows statistically significant correlations.

To establish the correlations between the radial increment and monthly values of temperatures and precipitation in particular years the moving response analysis (Biondi, 1997) was chosen. Due to the relatively short temporal climatic series (1961-2007) it was only possible to calculate the correlations for the period from 1995 to 2006. The DendroClim application requires that the minimal length of the intervals (moving intervals) is a double of predictors (17 in our case); therefore, the minimal possible interval of 34 years was selected.

The most statistically significant seems to be the positive correlation between the radial increment and temperatures in October of the previous year (starting in 2001) and mainly in March of the year in question for the entire period analysed. Also the negative correlation in June until 1998 is highly interesting. The other correlations do not present any longer tendency (**Table 3**).

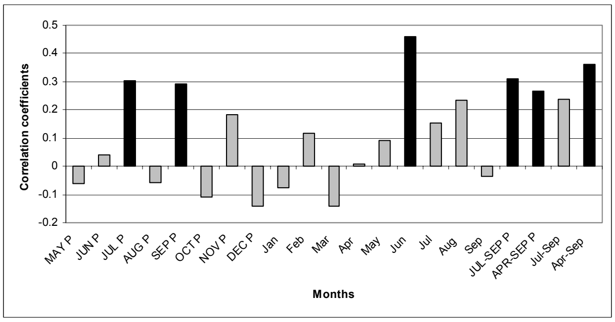

Fig. 4. *The values of correlation coefficients of the regional residual index tree-ring chronology with the average monthly precipitations from May of the previous year (P) to September of the year in question; moreover, the period of July-September of both the previous (P) year and the year in question and the vegetation period (April-September) of both the previous year (P) and the year in question were added for the period of 1962-2006. Values highlighted in black are statistically significant (α = 0.05).*

The precipitation presents, with one exception, only positive statistically significant correlations, only during the vegetation period. The correlations in July, August

Table 3. *The values of correlation coefficients for moving response of the regional residual index tree-ring chronology with the average monthly temperatures from May of the previous year (P) to September of the year in question for the period of 1962-2006. Values highlighted in black (negative correlation) and grey (positive correlation) are statistically significant (α = 0.05), moving intervals were used with the base length of 34 years over.*

	MAY P	JUN P	JUL P	AUG P	SEP P	OCT P	NOV P	DEC P	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1995	0.218	-0.371	-0.162	-0.125	-0.3	0.26	-0.071	0.081	-0.133	0.005	0.417	0.203	0.206	0.076	-0.018	-0.168	0.101
1996	0.185	-0.348	-0.299	-0.127	-0.226	0.259	-0.003	0.037	-0.069	0.028	0.418	0.276	0.098	-0.048	-0.029	-0.136	0.165
1997	0.188	-0.354	-0.329	-0.117	-0.264	0.263	0.01	-0.002	-0.112	0.035	0.431	0.229	0.119	-0.018	-0.042	-0.122	0.174
1998	0.202	-0.315	-0.327	-0.082	-0.258	0.234	0.034	0	-0.103	0.045	0.42	0.249	0.121	0.025	-0.019	-0.127	0.175
1999	0.222	-0.098	-0.213	-0.028	-0.19	0.219	-0.133	-0.058	-0.007	0.004	0.428	0.332	0.093	0.057	0.059	-0.16	0.3
2000	0.264	-0.119	-0.215	-0.001	-0.207	0.249	-0.1	-0.077	0.028	-0.021	0.437	0.274	0.085	0.048	0.082	-0.148	0.314
2001	0.305	-0.069	-0.215	0.07	-0.232	0.308	-0.015	-0.034	0.031	-0.015	0.432	0.274	0.118	0.001	0.082	-0.114	0.252
2002	0.316	-0.157	-0.163	0.147	-0.283	0.392	-0.109	-0.184	0.045	0.093	0.461	0.266	0.255	0.088	0.216	0.035	0.16
2003	0.187	-0.213	-0.24	0.077	-0.231	0.412	-0.171	-0.109	0.066	0.155	0.456	0.263	0.175	-0.068	0.152	-0.09	0.132
2004	0.171	-0.203	-0.242	0.049	-0.235	0.396	-0.173	-0.116	0.063	0.157	0.465	0.24	0.171	-0.052	0.152	-0.097	0.139
2005	0.178	-0.2	-0.238	0.074	-0.229	0.41	-0.167	-0.116	0.067	0.148	0.454	0.26	0.189	-0.06	0.167	-0.099	0.152
2006	0.137	-0.186	-0.257	0.085	-0.235	0.41	-0.159	-0.11	0.141	0.158	0.475	0.218	0.192	-0.135	0.057	-0.067	0.106

and September of the previous year and in June of the year in question are of essential importance. The June correlations of the year in question are statistically significant during the entire explored period, while statistically significant correlations of the previous year occur in some years only (**Table 4**).

The regional standard tree-ring chronology shows an obvious decrease in the radial increment in the second half of the 1970s and the beginning of the 1980s. The lowest values of increment are found for years 1976, 1980, 1988, 1992, and 1993. These years with low increment were also confirmed by the analysis of significant negative years (**Table 5**). Starting in 1996 there is an obvious increase in increments which is interrupted only in 2000. Another decrease comes in 2003 and 2006 (**Fig. 5**). The results of the analysis of the significant negative years show that the highest growth depressions were in 1980 and 2003, when 60-80% of all trees responded in this way. The possible explanations for the low increments in particular negative years are presented in **Table 5**.

The results of the habitual diagnostics from the explored area were confronted with the results from other mountain ranges of the Czech Republic (**Table 6**). The table shows the very low percentage of secondary shoots and low degree of crown transformation. This also corresponds with the little representation of resilient trees and damaged, heavily transformed trees (**Fig. 6**).

The development of salvage cutting connected with the observed decline is presented in **Fig. 7**. The graph shows the first cutting in 2001, therefore, we can conclude that the stress factor or factors started to gain their

Table 4. *The values of correlation coefficients for moving response intervals of the regional residual index tree-ring chronology with the average monthly precipitations from May of the previous year (P) to September of the year in question for the period of 1962-2006. Values highlighted in black (negative correlation) and grey (positive correlation) are statistically significant (α = 0.05), moving intervals were used with the base length of 34 years over.*

	MAY P	JUN P	JUL P	AUG P	SEP P	OCT P	NOV P	DEC P	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1995	0.161	-0.038	0.207	0.337	0.184	-0.254	0.091	-0.074	-0.015	-0.058	-0.133	0.129	0.217	0.307	0.14	0.346	-0.143
1996	0.123	0.02	0.26	0.286	0.102	-0.189	0.038	0.005	0.04	-0.01	-0.071	0.133	0.263	0.316	0.113	0.255	-0.303
1997	0.149	0.004	0.23	0.294	0.155	-0.192	0.073	-0.02	0.013	-0.029	-0.087	0.14	0.291	0.309	0.166	0.254	-0.314
1998	0.187	-0.012	0.245	0.281	0.163	-0.179	0.088	-0.021	0	-0.023	-0.078	0.123	0.287	0.309	0.139	0.226	-0.269
1999	0.113	0.039	0.171	0.134	0.248	-0.065	0.077	-0.085	-0.061	0.041	-0.104	0.086	0.212	0.455	0.089	0.085	-0.327
2000	0.095	-0.01	0.178	0.149	0.254	-0.046	0.084	-0.075	-0.048	0.024	-0.126	0.088	0.199	0.444	0.062	0.079	-0.311
2001	0.06	-0.063	0.229	0.092	0.256	-0.064	0.081	-0.093	-0.044	0.034	-0.13	0.121	0.174	0.47	0.099	0.06	-0.224
2002	-0.008	0.035	0.315	0.028	0.355	-0.135	0.16	-0.088	-0.075	0.115	-0.112	-0.019	0.235	0.441	0.064	0.174	-0.144
2003	-0.065	0.012	0.315	-0.066	0.293	-0.179	0.178	-0.059	-0.091	0.157	-0.113	0.024	0.203	0.507	0.049	0.241	-0.098
2004	-0.063	0.022	0.319	-0.042	0.306	-0.174	0.191	-0.058	-0.087	0.138	-0.124	0.025	0.208	0.502	0.054	0.241	-0.083
2005	-0.079	0.017	0.32	-0.064	0.297	-0.18	0.196	-0.071	-0.085	0.171	-0.122	0.003	0.211	0.499	0.055	0.241	-0.11
2006	-0.095	0.058	0.342	-0.09	0.335	-0.112	0.192	-0.198	-0.095	0.177	-0.133	-0.07	0.192	0.515	0.101	0.197	-0.041

Table 5. *Negative pointer years and climatic characteristics which may be interpretation of the years. White field, black number – 20-40% of trees sampled; grey field, black number – 40-60% of trees sampled; black field, white number – 60-80% of trees sampled.*

Negative pointer year	Abnormal climatic characteristics
1962	*without abnormal climatic characteristics*
1963	high temperatures in July, low precipitation from January to April
1965	subnormal temperature in April, low precipitation in March
1976	low temperatures in March, subnormal precipitation in March and April
1980	low temperatures from March to May, subnormal precipitation in March and May
1988	low temperatures in March
1992	high temperatures from June to August, low precipitation from May to August
1993	low precipitation from April to May
2003	high temperatures in June and August, low precipitation in February, April, May, June, August
2004	subnormal precipitation from April to May
2006	high temperatures in June and July, low precipitation in July

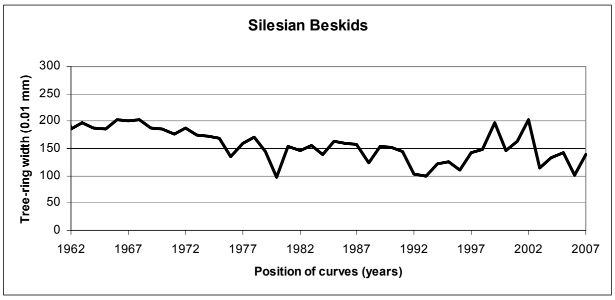

Fig. 5. *Regional standard chronology from the Silesian Beskids*

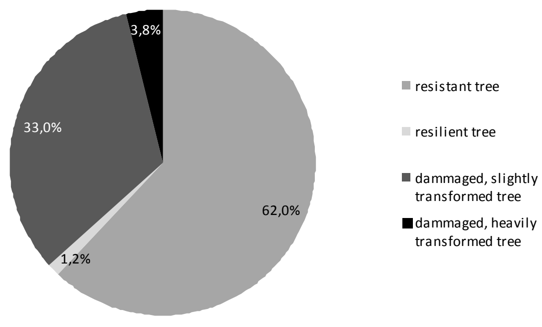

Fig. 6. *The distribution of categories of tree stress response in the explored area*

mortality effect in this or the previous year (dead trees are felled with some delay).

4. DISCUSSION AND CONCLUSIONS

The curves of the regional standard chronology are characterized by the constant decrease in radial increment (**Fig. 5**). There are noticeable growth depressions, especially in the second half of the 1970s and at the beginning of the 1980s. After 1996 there is a steep rise of the increment, which is interrupted in 2000. A two-year period of increased radial increment follows, interrupted again in 2003 and 2006. After 2003 the increments did not achieve the values from the turn of the millennium. The regional standard chronologies presented in this study confirm the existing knowledge about the increment of now adult stands of *Picea abies* in the Beskids. The same tendency, in basic features, was found out by Feliksik and Wilczyński (2000), Wilczyński and Feliksik (2005), both in the Polish Western Beskids and Šrámek *et al.* (2008) in the same area as was examined in this study.

The radial increment of spruce in forest district Jablunkov correlates significantly with precipitation rather than temperatures, which is an expected result. The area of the Silesian Beskids, as well as the entire Central Europe except peak sections of higher mountain ranges, presents no temperature-related problems for the spruce. The precipitation more often falls to the critical values, therefore it correlates with the increment more closely (Mäkinen *et al*., 2002). The ring width correlated positively with monthly precipitation in July and September of the previous year (**Fig. 4**). Positive correlation was also found with the precipitation during the vegetation period, i.e. April–September, and during summer, i.e. July-September (**Fig. 4**). In particular years, the growth correlated significantly with precipitation in the months of July, August, September (**Table 4**); the character of the distribution of these correlations in particular years indicates that the determining period is the period of July-September as a whole. The positive influence of precipitation in the vegetation period of the year preceding the ring growth was also documented for spruce in forest district Bukowiec (Feliksik, 1993); the positive influence of precipitation in June–July is mentioned by Pichler and Oberhuber (2007). The probable explanation for the correlation is the positive influence of this precipitation on the production of nutrients, which are then used for the growth in the initial stage of ring creation. The precipitation during the vegetation period of the preceding year, especially the end of the season, also influences the disposable water in the soil in spring.

Further, the ring width is positively correlated with monthly precipitation in June of the year when the ring was created, and with the precipitation during the vegetation period (**Fig. 4**). Positive correlations of precipitation in June and July are documented for the Polish part of the Beskids (leśnictwo Pierściec) by Feliksik *et al.* (1994). Similar results were found at other sites as well. Vitas (2004) from drier locations in Lithuania and Mäkinen *et al.* (2001) from the south of Finland give evidence on the correlation of the radial growth of spruce with June precipitation. Koprowski and Zielski (2006) in the north of Poland and Desplanque *et al.* (1999) in lower altitudes of the French Alps found correlations with precipitation of May–July. The substantial part of a tree ring in the Beskids is formed from May to July, therefore, the comfortable supply of water is of high positive significance, the key month being definitely June. The influence of spring and early summer precipitation has been rising in the last about 10 or 15 years, due to the increase in solar radiation and the frequency of high temperatures (thus also the rise of evapotranspiration). This is confirmed by the values of June correlation coefficients for individual years, or their increase after 1998 (**Table 4**).

The ring width significantly correlated in the positive way with the temperature in October of the previous year (**Fig. 3**). The same correlation was found out in the Polish Tatras by Savva *et al.* (2006). Good conditions for photosynthesis may have led to a more intensive storage of carboxyhydrates and thus support the growth in the following year. The reason why this influence was considerable could also be that October average temperatures had quite a high variability ranging from 5.8°C to 13.3°C and in this way created highly variable conditions for the photosynthetic activity. A higher average temperature in October is often the consequence of a more balanced procedure of day temperatures without any steep and

Table 6. *The comparison of results (average values) of habitual monitoring (according to Cudlín et al., 2001) from various mountain ranges of the Czech Republic*

Monitoring area	Total defoliation (%)	Defoliation of primary structure (%)	% of secondary shoots	Degree of crown transformation	Yellowing (%)	Browning / rusting (%)	Injury to stem
Slezské Beskydy - Silesian Beskids	35.06	52.32	26.82	0.62	1.98	0.20	0.41
Drahanská vrchovina Highlands (unpublished)	36.47	59.83	36.58	0.95	0.00	0.00	0.15
Orlické hory Mts. (Žid *et al*., 2007)	38.86	65.84	44.39	1.27	2.44	1.84	0.68
Krušné hory Mts. (unpublished)	31.25	59.25	29.50	0.88	-	-	-
Krkonoše Mts. (Cudlín *et al*., 2001)	45.00	84.33	76.33	2.88	-	-	-

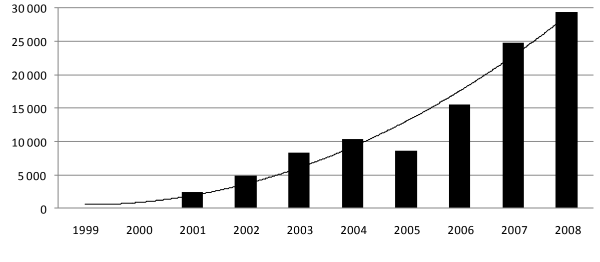

Fig. 7. *The development of salvage cuttings connected with the decline of Picea abies in Forest District Jablunkov (m^3) with a polynomial trend line*

sudden decreases. Such weather allows for a more continual and gradual transition of spruce to dormancy. In individual years (**Table 3**) significant October correlations were found for years 2001-2006. In 2001 first larger dying of trees without any obvious signs of damage started to appear and these trees were felled in salvage cuttings (**Fig. 7**). It is possible that the significance of October temperatures rose in relation to the deteriorated vitality of trees. In other words, the transition of weaker trees to dormancy is more strongly connected with the sufficient supply of carboxyhydrates as their capacity to compensate for the handicap is smaller.

Moreover, the ring width is significantly positively correlated with the temperature in March of the year in question (**Fig. 3**). The same correlation was documented in Lithuania at various sites by Vitas (2004), in south of Poland by Koprowski and Zielski (2006), and in the Polish Tatras by Savva *et al*. (2006). The correlation of March temperatures with the radial increment was also found out at two sites of ICP Forests (Mze ČR, VÚLHM, 2004) in the Podbeskydská vrchovina (Lower Beskids Highlands) and the Moravskoslezské Beskydy (Moravian-Silesian Beskids). A positive influence of temperatures of March-May was also stated for the Polish part of the Beskids (Feliksik *et al*., 1994). In March the spruce photosynthetic capacity is revived and higher temperatures bring better conditions for this revival, e.g. the soil thaws earlier. A higher average temperature also means lower risks, e.g. a lower probability of the occurrence of night frosts and consequent damage.

Many studies, especially those from higher altitudes of mountains, established a positive correlation of the growth with temperatures in summer months, specifically mainly in May, June or July (Mäkinen *et al*., 2001; Savva *et al*., 2006; Büntgen *et al*., 2007). However, the examined areas of the Silesian Beskids do not show a significant correlation between the growth and the temperature in these months and in June this correlation is even negative (**Fig. 3**). This situation shows that : i) what is critical for the growth of spruce in these altitudes in summer is precipitation, not temperature; temperatures are significant at higher altitudes only; ii) there is a negative relation between monthly precipitation and average temperature, i.e. a colder June is also usually rainier.

The results of habitual monitoring (**Table 6**) show an interesting proportion of resistant trees and damaged, slightly transformed trees (**Fig. 6**). The degree of transformation was generally low, lower than in other mountain ranges of the CR that have been monitored (**Table 6**). The lower degree of the damaged assimilation apparatus replacement can point to a relatively short stress, i.e. to the first induction (signalling) stage of tree response to stress, when the loss of vitality is demonstrated and the repair ability is low. The low creation of secondary shoots can also be a consequence of the high intensity of stressors.

The total defoliation was of average degree within the context of the CR, which is seemingly in contrast to the progressive character of the decline described above. Dead and dying trees with unspecific signs of decline started to appear in the location after 2000. Typically, it was a fast procedure of health deterioration when the trees went yellow, defoliated and in some cases died within one or two vegetation periods. These dead or heavily damaged trees were removed within salvage cuttings and first recorded as “dead trees without attack”, and starting in 2008 for unspecified reasons as “salvage cutting, tracheomycosis (*Armillaria spp.*)” disrespecting whether tracheomycosis or putrefaction, micelial fans or rhizomorphs of *Armillaria* spp. were present or not (**Fig. 7**). The rising tendency of the cuttings is obvious. Therefore, the dying trees were not recorded in the habitual monitoring as they had been felled before, in spring. In spite of that, it can be concluded that the habit of trees corresponds with the development of salvage cuttings and with the hypothesis about the strong stress load or its considerable increase in 2003 and the following years.

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